2 Thinking outward

Heuristics for systemic understanding of environmental problems

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1 Introduction

In the face of sustainability challenges, the limits of reductionist thinking are widely recognized. The rise of modern environmental discourse half a century ago can be portrayed as a response to the unresolved issues left by reductionist science. Since then, many environmentalists have systematically challenged the scientific tendency to split complex phenomena into simplistic analytical models and thereby isolate objects from their environment. This 'paradigm of simplification' (Morin 2008) is seen as incapable of recognizing the complexity of environmental issues, and it is considered to lead to inappropriate policy solutions that frequently fail to reach sustainability (e.g Ostrom 2009). A classic example of this paradigm in environmental management is the widespread separation between the elements of the ecological environment – water, air and soil – and their treatment accordingly (e.g. Miller 1996).

During the last decades, holistic approaches to the human–environment relationship have become institutionalized in academia, including the fields of human ecology, ecological anthropology, environmental geography, ecological economics, and so on. 'Holism' encompasses approaches to scientific inquiry that investigate complex systems whose behaviour cannot be understood by studying the individual components of the system in isolation. While reductionism strives for insight that is independent of the context in time and space, holism, in contrast, strives for insight that embraces and explains the context and complexity (Sarewitz 2010). Neither approach, however, provides analytical tools to understand or deal with complexity as an emergent and variable property of an open system, resulting from intricate interactions amongst multiple components which are not necessarily complex in themselves. These interactions produce the 'higher-order' properties which make the system what it 'is', for the time being (Cilliers 2010; Prigogine and Stengers 1984).

Since complex systems cannot be defined conclusively – indeed, there is no stepping outside complexity – all holistic descriptions of human–environment interaction are based on a model of this interaction, which necessarily reduces the complexity of the systems. There is no objective way to do this reduction; instead, a series of choices behind particular approximations of the whole is needed with respect to how to define the system, what system functions and outcomes are important, what measures to take to make things better, and what is considered an improvement (Sarewitz 2010; Ison 2010). A holistic description developed for one context may not be optimal for another. However, those who are developing or applying a particular approach are not usually weighing the choices behind their system definition against other possible definitions. Thus, particular ways to define systems easily become reified so that they are understood as existing independent of our conceptualizations of them. An example is the mainstream position wherein ecosystems are literally taken as natural units, systems created by nature. The concept of ecosystem, however, is a specific way of perceiving a complex set of interactions in nature. Like all system approximations, conceptions of ecosystems involve boundary judgements by an observer (Ison 2010, 2011).

In this chapter, we argue that dealing with environmental sustainability requires a systemic, yet open-ended approach to human–environment interaction. Interconnections are a key for such understanding, but it depends on the perspective and purpose which connections matter and are taken into account (Ison 2010). Our primary goal in this chapter is to contribute to the *general capacity* of transdisciplinary inquiry to capture environmental issues as emergent and systemic features of human–environment interaction. Instead of proposing a theoretical account of which interactions matter and in what way, we focus on the cognitive search process through which relations between components can be explored. We call this strategy *outward-oriented thinking*, as the simple idea is to define and make sense of an issue by looking outwards rather than inwards from it, that is, by looking at its relations to other systems either 'beside' or 'above' it. Following this operation, the logic of analyzing the issue may change; the initial objects of interest transform into different entities; and the issue becomes understood in novel ways.

We will illustrate this strategy through three heuristic variations, which aim at facilitating systemic understanding of environmental problems across contexts, while remaining sensitive to the unique nature of each problem situation. Each heuristic provides an orientation framework for making connections amongst a range and diversity of factors in order to create a comprehensive and purposeful understanding of environmental issues. First is a systemic framework for identifying and categorizing human-induced environmental changes; second is a process model of what constitutes an environmental problem; and third is a generic checklist for aspects of environmental issues that deserve systemic consideration. Before going into the strategy of outward thinking and its heuristic variations, we make a case for systems thinking in transdisciplinary environmental and sustainability research.

2 Environmental problems in systemic view

Systemic thinking refers to the understanding of a phenomenon within the context of a larger whole (e.g. Ison 2010). It is a constitutive aspect of all environmental sciences, as their focus on 'environment' rests on the assumption that the elements and processes we observe in nature are connected to each other in ways that deserve integrated consideration. Implications of this assumption range from the recognition of complex causation in ecological processes (e.g. Levin 1992) to ethical principles for holistic nature conservation (e.g. Leopold 1949). However, a higher degree of systemic thinking came to characterize the problem-centred discussion of environment that arose in the 1960s. This entailed broader consciousness about the ways in which human activities are embedded in ecological systems, which, in turn, are threatened by increasing human influence. Especially after the publication of *Silent Spring* (Carson 1962), our environment as a vulnerable whole became an issue and an object of public attention and scientific research. This image was epitomized by the early pictures of our planet seen from space.

Along with the rise of broader environmental consciousness, the importance of a holistic view was recognized. The 1972 report commissioned by the Club of Rome, *Limits to Growth* (Meadows et al. 1972), emphasized the interconnectedness of economic and socio-cultural problems with ecological ones, and a bestselling book of ecology, *The Closing Circle* (Commoner 1971), suggested that the American economy should be restructured to conform to ecological laws. Another systemic view was the Gaia hypothesis (Lovelock 1979), according to which the Earth was assumed to function analogically to a living organism. These accounts set the stage for a systemic approach to environmental issues, which is today often categorized under the rubric of sustainability science.

In the dominant understanding of sustainability, the global environment is represented as a set of systems of varying scales and levels of resolution and complexity (e.g. Kates et al. 2001). The study of social-ecological systems (Ostrom 2009), for example, observes the use of natural resources by exploring relationships between resource systems, resource units, resource users and governance systems. For another example, industrial ecology (e.g. Ayres and Ayres 2002) observes the interaction of industrial systems with the biosphere by using natural ecosystems as a metaphor for environmental sustainability. Such frameworks capture environmental problems from a systemic perspective: problems are not viewed as isolated instances that need to be solved; instead, they are viewed as relationally constituted by a number of non-linear interactions and various feedback loops that are the causes and effects of each other.

However, a different set of ontological arguments concerning environmental issues have been made since the 1990s, drawing on a range of intellectual traditions including science and technology studies, social anthropology, cultural geography, political ecology and poststructuralist theory (e.g. Liverman 1999). They show that the scientific models of the environment are shaped by political assumptions and cultural values, and argue for an awareness of the limitations of scientific expertise and for the recognition of the importance of local and indigenous knowledge of the environment. These studies have raised fundamental questions concerning the very distinction between the natural and the social, and offered explanations for how such categories are themselves socially produced (e.g. Jasanoff 2004; Latour 2004). According to Barry and colleagues (2008), the studies of environmental issues as socially constructed are in an agonistic or antagonistic relation to environmental science, as they make claims that contest or transcend the epistemological and ontological assumptions made by environmental scientists.

At the same time, the growing poststructural interest in the environment has brought a new sense of context to environmental issues – that of our systems of observing and dealing with them. While it clearly does not support the systemic understanding of environmental problems as environmental science has it, the two perspectives can be understood to operate at different logical levels. Whereas environmental sciences investigate the dynamics of human–environment interaction at a 'first-order' level of observation, their critics in the poststructural tradition incorporate a new set of variables into the analysis, which opens up a new 'level' of observing the problematique. In this sense, the relationship between the two perspectives is not negation, but self-reference (see Ison and Russell 2000). What appears as critique of the first perspective simply offers a meta-point of view, which integrates the observer in its observation (Morin 2008: 51). Such a meta-view, however, can itself be observed from another point of view – the self-referential cycle continuing *ad infinitum*.

This kind of layered view of the different concerns and claims about environmental issues illustrates the transdisciplinary potential of the systemic approach. Its promises to environmental problem solving are somewhat different, or lie elsewhere, than is implied by most first-order descriptions of human–environment systems. First, those systems do not exist in the world 'out there', but are brought forth in the process of our observing and acting in the world (Schlindwein and Ison 2004). This highlights the ability of systemic inquiry to tackle the conceptual or epistemological complexity of environmental problems and thus 'avoid the worst excesses of living in a projectified and programmatic world' (Ison 2010: 246). Second, and following from the first point, the way in which a system gets defined is not a passive description of reality, but an active construction of opportunities for thinking and acting upon it (see Law 2004).

These insights are in line with the 'design turn' in systems thinking, which changes the focus from the ontological status of systems to their heuristic functions and technologies for social learning. Conceptualizing a complex set of interactions as a system is an effective way to bring out different approaches, reframe situations and problems, and set out thinking and acting in purposeful ways (Ison 2010). The Gaia hypothesis and the models of the Club of Rome, for example, may not be scientifically rigorous, let alone 'empirically testable', but they offer heuristic constructions that sensitize us on planet-scale considerations. In general, operating at a systemic level increases the likelihood of finding ‘leverage points’ that enable radical intervention in problems instead of mere incremental improvement (Meadows 1999).

3 Outward thinking as a tool for systemic understanding

As a strategy for coping with the cognitive or conceptual complexity we experience in the face of environmental problems, we discuss a simple ‘search rule’: look outward from the initial object of interest, and attempt systemic understanding at a new level. We call this strategy ‘outward thinking’, and propose it as a potential cognitive orientation for dealing with complex phenomena. Because of its simplicity, we suggest that it is helpful in detecting and correcting common shortages in environmental research, politics, education, administration, and so forth, and especially in their ‘inward-looking’ organizational logics that fail to acknowledge and address complexity. Outward thinking can lead to the invention of new categories or rearrangement of established categories. It is a generic tool for finding an appropriate framework that allows one to make claims that matter within a given context or problem situation.

The operational principle of outward thinking is its active alignment of the object of interest with other entities either ‘beside’ or ‘above’ it. The latter attributes refer to logical levels of observation that can only be defined in relation to a particular system of interest. Any framing of an issue or a problem makes some alignments, but often they are embedded in a given problem definition rather than critically reflected. From the perspective of epistemological complexity, environmental problems can be described and intervened in a number of different ways, all of which entail a particular set of cognitive alignments. It is thus possible to actively search for alignments that allow one to frame problems in insightful ways. This is in line with the strategy of *deconstruction* which investigates the structural conditions for meaning in any system. Once these conditions have been identified, it becomes visible that they could also be different, thereby displacing the meaning generated in the system (Cilliers and Preiser 2010: 291). In order to avoid premature categorization and reaction to complex problems ahead of us, we need cognitive tools for organizing that complexity and finding the most effective entry points to them.

Outward thinking is based on ideas similar to those behind ‘lateral thinking’, developed by Edward de Bono (e.g. 1970). According to de Bono, typical Western reasoning follows ‘vertical’ logic, in which the object of interest is narrowed down into a given perspective or phenomenon, and the thinking proceeds logically from the given object to another. As this hinders new inventions and insights, he suggests a strategy of consciously re-directing thinking away from this path and towards more surprising directions. Unlike de Bono, we do not suggest searching solutions from the most unlikely direction or to breaking the patterns of logical thinking. Rather, the idea of outward thinking is to systematically and logically map the world outside a

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given object of interest, or beyond the assumed boundary between the object and the rest of the world. We then broaden the scope of attention to include those objects and issues that lie outside the original object of interest, and try to find commonalities of structure and processes despite the appearance of difference.

Outward thinking can be seen as the opposite of 'inward thinking', of which the reductionist method of science is the most profound example. It can be argued that inward thinking has led to a fragmented understanding and treatment of environmental problems, including the way environmental regulation is designed and implemented. Even environmental sciences have not avoided this tendency. Despite their explicit attempt to integrated analyses, they tend to limit attention to one 'problem' at a time, which diverts attention from the interconnections between them. Some humanities approaches to the study of environment do not share the scientific tendency of splitting phenomena but rather aim at a holistic engagement with them (Frodeman, Chapter 11, this volume). Our strategy of outward thinking has thus less to offer to those traditions, except for making the contributions of environmental sciences more accessible or interesting to them, and vice versa.

Overall, different approaches offer different heuristics for defining problems and finding solutions, but the richer our heuristic repertoire is, the higher our capacity to deal with complex problems is. For example, carbon dioxide emissions and their consequences can be analyzed by sector or source, but also as systemic outcomes of life styles or social structures. Combining both approaches obviously captures more than either one of them. Outward thinking might serve as a cognitive strategy for shifting across approaches, and particularly for environmental sciences to move closer to the humanities without losing sight of the causal accounts provided by the reductionist method.

3.1 Directions of outward thinking

The practice of outward thinking can be illustrated by making a distinction between two directions: horizontally 'sideways' on the one hand and vertically 'up' on the other. The idea is that the inquirer moves from the original point of observation to another point, which allows him or her to situate the object of interest in a wider context and re-conceptualize it in relation to other phenomena in that context.

In *horizontally* directed thinking, the inquirer searches for comparable entities with a view to identifying commonalities or relations between different entities. As an outcome of horizontal thinking, the inquirer can construct a model which incorporates the new components and relations into a procedural or structural assemblage, for example. Procedural models link various events into temporally or causally connected sequences (see Musters et al. 1998: 250; European Environment Agency 1999: 9), whereas structural models assemble several parallel factors into a common structure (e.g. Tapio and Willamo 2008). The key is to search for comparable systems outside the original system of interest and then systematically detect conceptual or causal interrelations between them. The concept of sustainable development serves as an example of horizontal thinking: it incorporates parallel systems, such as economic, socio-cultural and ecological, into a common frame, which allows for an integrated analysis of previously separated entities.

In thinking *vertically up*, the inquirer can set out to explore, for example, a particular environmental issue as a part of a wider system, such as environmental conservation within a country or a more profound sustainability crisis. The aim is to capture new elements of a particular issue by looking at it in the light of a higher-level system. This enables the inquirer not only to recognize other comparable systems, but also to focus on possible generic mechanisms or patterns that apply to many concrete phenomena (see Zerubavel 2007). Climate models, for example, strive for finding higher-level patterns that emerge from the coupled dynamics of atmosphere, oceans, land surface and sea ice.

Another aim of thinking upwards is to establish a relationship between the constituent parts of a system and the system as a whole, and thus enable analysis and conscious movement between the two system levels. This involves acknowledging the dialectical relationship between knowledge and the system within which it is constituted (Cilliers 2010; Morin 2008). Analyzing parts within the context of a whole opens up a new perspective, and vice versa – analyzing the whole from the perspective of its constituent parts is a useful 'test' of appropriateness for the way in which the given whole is defined.

3.2 Stages of outward thinking

In addition to the distinction between horizontal and vertical directions, another pair of concepts can be used to characterize outward thinking: the distinction between the stages of extension and integration. *Extension* refers to the widening of the scope of attention by embracing either new elements 'neighbouring' the original focus of attention, or a new level of analysis that is logically 'above' the original level, thus enabling analysis in a broader context. By *integration* we refer to the analysis of interaction between the various components of a system, as well as between the components and the system as a whole. This allows for emergent properties and insights to arise.

Extension and integration are temporarily coupled in the sense that extension is the first step of outward thinking, followed by integration of new observations with the initial ones. During the integration, elements are blended together in order to form a new perspective or object of analysis. This cycle can then be repeated by widening the scope of attention again into a new direction or to a higher systemic level. The alternation of extension and integration constitutes the core of outward thinking, and it can be carried on

Table 2.1 Stages of outward thinking in horizontally and vertically oriented search.

	Horizontal thinking	*Vertical thinking*
Extension stage	Widening the scope of attention by searching for other entities at the same systemic level, either parallel or successive to the original object of interest	Widening the scope of attention by searching for a more general level of meaning within which to situate the original object of interest
Integration stage	Integration of new entities with the initial ones by searching for conceptual or causal linkages between them	Creating a systemic account of an issue by searching for structured interactions it is a part of, and the emergent properties that arise at a higher systemic level

Notes: Note that the cognitive operations described in the table refer to context-specific levels and categories, not to universally valid structures.

as long as there is a desire to enrich the perspective or broaden the system under consideration. Table 2.1 presents the stages of outward thinking in horizontally and vertically oriented thinking.

Cases of horizontal thinking, in particular, abound in the history of environmental conservation. An example is the extension of the concept of pollution in Finland and some other European countries. Pollution was first recognized as a problem in aquatic environments, followed by ambient air, and finally by soil; after this gradual extension of problem framing, an integrated approach to pollution prevention was adopted (Hagenah 1999: 17–18; Laukkanen and Huutoniemi 2006). Another example of this pattern is the development of theoretical understanding of the forest decline in Central Europe during the 1970s and 1980s, indicated also by the changing content of environmental textbooks. Explanations for extensive forest damages were first searched for by extending the analysis to cover several potential reasons one by one. After this phase, an idea of multiple simultaneous causes was developed and soon transformed into a new framework, that of multiple stress theory (Nuorteva 1990: 7; Willamo 2005: 139).

The dominant mode of analytical thinking, the process of *demarcation and compartmentalization*, or what Morin (2008) has called ‘disjunctive thinking’ can be illustrated in the same way. In this case, the first step is to select and narrow down a topic of interest, followed by breaking it down into its constituent parts by, for example, classification. Thereafter the inquirer takes a closer look at some of these categories by separating them from other things. Also this process, that is, consecutive demarcation and compartmentalization, can be continued until a desired level of accuracy and simplicity is reached. For a comparison of this process and the process of outward thinking, see Figure 2.1.

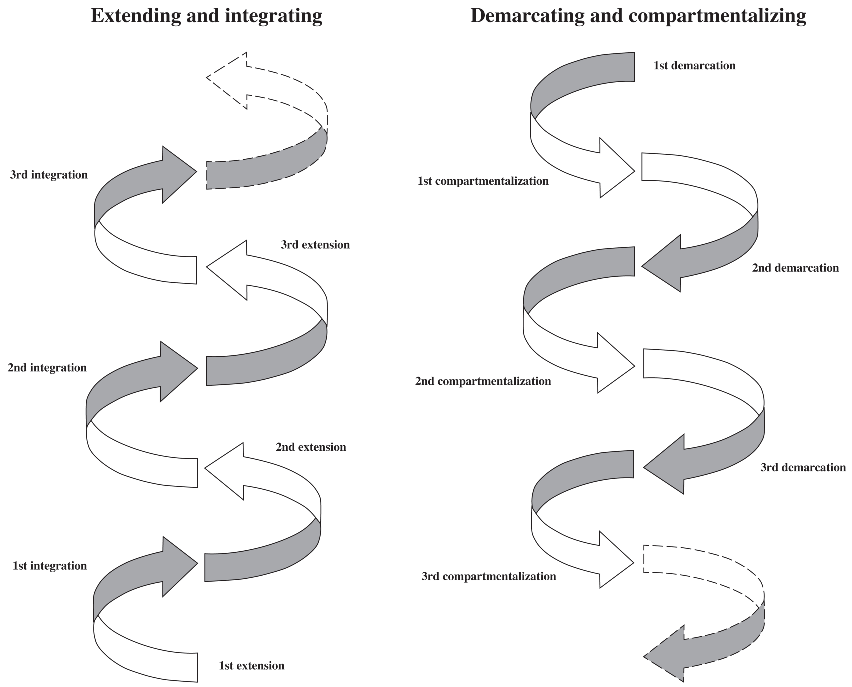

Figure 2.1 Processes of extending and integrating as well as demarcating and compartmentalizing (modified from Willamo 2005: Figure 10).

Both inward thinking and outward thinking are essential parts of human knowledge production and sense-making. However, the history of environmental sciences suggests that the process of narrowing and disintegration may result from an unaware or unreflective selection of a viewpoint, subject matter, or assumption in research or education, for example. Framings that are products of historical and to some extent idiosyncratic processes are easily taken for granted by researchers and students, who thus never question their relevance but direct their attention accordingly. Particular meanings given to things start to dominate thinking and action, and the conceptual grip on interactions across institutionalized categories may be lost. Moreover, some categories are often picked up and analyzed in further detail, while others are set aside (Bowler 1992). This process characterizes the institutionalization of knowledge, both intended and accidental, but the outcome has usually been towards more fragmented and reified accounts of environmental problems.

4 Heuristics for systemic understanding of environmental problems

In what follows, we discuss three heuristics designed to combat the tendency of reductionist or disjunctive thinking and facilitate more comprehensive understanding of environmental issues through outward thinking. The heuristics help make sense of various environmental problems by detecting their connections to the broader realm of human–environment interaction. They suggest 'lumping rather than splitting' as an overall style of theorizing (cf. Zerubavel 2007). We do not present them as 'theories' of environmental problems, but as more generic tools that may be used to guide analysis of particular environmental issues, or to inspire further investigation of their complexity. All these heuristics have been applied to such purposes (e.g. Berninger et al. 1996: 45–47; Lyytimäki and Tapio 2009; Manninen and Willamo 1993; Nygrén et al. 2012; Varho et al. 2013). What is interesting here is the logic of these heuristics, that is, the conceptual or cognitive work they do in organizing our attention in environmental problem solving.

4.1 Search tool for human-induced environmental change

The threats of modern human activities to environmental sustainability are numerous and interconnected. They include issues such as habitat destruction and biodiversity loss, deforestation, degradation of the oceans, scarcity of fresh water for a growing population, depletion of resources, toxic synthetic chemicals accumulating in the environment, anthropogenic climate change, etc. (Murphy 2012). If we start to make a list, it quickly becomes clear that it is potentially endless, and any attempt to prioritization is likewise an enormous task. Moreover, environmental issues do not seem to have much of a pattern at all, but are often perceived as a miscellaneous set of undesirable changes in the natural environment.

Frameworks that aim at systematic presentation of environmental problems do exist. They can be used to sort out environmentally harmful human activities, sources and types of emissions, various ecological effects, and so forth. Perhaps the most traditional scheme of describing environmental problems is their categorization into issues pertaining to environmental degradation on the one hand and to natural resources and conservation on the other (e.g. Miller 1979: 6–12). From the viewpoint of epistemological complexity, a shortcoming of the existing frameworks is their reliance on a fixed set of categories drawn from prevailing knowledge of environmental problems. A further inspection of most categories reveals that they are arbitrary, and they could also be different. What we find lacking in these classifications is an explicit criterion for inclusiveness. In other words, a criterion is needed for deciding which activities, emissions, effects and so on should be included in the environmental analysis. At the same time, major risks for the environment – such as the increase of artificial light at night (Lyytimäki and Rinne 2013) – may go unnoticed partly because they do not fit into the prevailing categories of environmental problems.

Thus, a central weakness in the concept and practice of environmental protection is the fluid understanding of what constitutes an environmental problem in the first place, and thereby a lack of systemic overview of the problematique. We propose that the situation could be enhanced if the underlying

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similarities between, say, the taking of gravel, chemical pollution, hunting, nocturnal lighting, and other nature-burdening activities were better understood. The lack of systemic approach to human-induced changes in the environment may result in a total unawareness of a certain type of environmental change, such as the emissions of light or of potential or kinetic energy. For example, little attention is paid to the way in which masses of water in reservoirs cause strains in earth surface, and thereby their potential influence on earthquakes (see Gupta 2002). Even when such environmental changes and risks are recognized, they are not systematically linked to other environmental concerns and thus easily remain unattached to the realm of environmental protection. For example, the fact that masses of hedgehogs are killed by road traffic is typically perceived as an environmental issue (e.g. Huijser and Bergers 2000), whereas people's death in traffic accidents is categorized as a road safety issue. At the same time, the effects of air pollution on all living organisms are perceived as environmental issues. This imbalance implies that a moving car is not recognized as a discharge of kinetic energy in the same way as sulphur dioxide is recognized as a chemical discharge.

As a solution to this arbitrary conception of what counts as an environmental problem, we propose a heuristic tool for identifying and categorizing human-induced environmental changes. This tool uses ecological interaction at the interface between human systems and natural systems as its starting point, and focuses on the direct influences of the former on the latter. The idea is that we can conceptualize all environmental problems as resulting from either a *discharge* from human systems to ecological systems, or an *intake* from ecological systems to human systems. 'Discharges' and 'intakes' are anything that matter in ecological terms. This is not to say that such influences are always problematic, or that all environmental problems can be explained by these concepts, but that they provide both search heuristics and boundary judgements for identifying potential environmental problems.

Borrowing the logic of ecosystem ecology (e.g. Odum 1971), the heuristic tool distinguishes between four systemic levels at which humans change their environment: (1) energy and its flow, (2) abiotic matter and its circulation, (3) living matter including its structures and functions, (4) mechanical macro-level constructions and functions, such as soil and bedrock structures, water systems, and the flow of water and air. Human action brings on changes at all levels, and together these changes constitute the human influence on nature as a systemic whole. Discharges and intakes can thus be comprised of energy (e.g. warmth, sound), matter (e.g. carbon dioxide, phosphorus), living matter (e.g. genes, individuals of a certain species), or macro-level structures (e.g. reservoirs, gravel ridges).

This categorization aims to cover all levels of ecological occurrence. In systems language, these levels are distinguished from each other by an ecologically defined complexity threshold. Due to the different nature of events occurring on different levels, they are not always recognized as various forms of human-induced change in the ecological system. The flow of energy

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can be grasped by physics' concepts, the circulation of matter by chemistry tools, and so on. One has to actively look outward from a single conceptual framework in order to uncover the commonalities between, for instance, the 'discharge' of kinetic energy from a moving car and a discharge of sulphur dioxide from an industrial plant.

This heuristic draws on classifications and models used in, for example, textbooks about environmental conservation, but aims at a broader and more coherent overview of the multiple ways humans influence nature. It can be understood as an extension of the systematic analysis of material flows (Schmidt-Bleek 1993), which is based on a similar idea of *inputs* from geo- and biosphere to technosphere (natural resources) on one hand and *outputs* from technosphere back to geo- and biosphere (pollutants) on the other. However, while both 'natural resources' and 'pollutants' tend to be understood in traditional terms, and consisting of matter only, our heuristic scheme is designed for detecting all kinds of ecological exchanges, including energy, living matter and macro-level structures. This is an important contribution, given that chemical pollutants have clearly dominated environmental discourse over energy discharges, as exemplified already by the debate raised by Rachel Carson. An exception of this pattern is the attention paid to the radiation caused by nuclear energy, especially related to the Chernobyl disaster in 1986.

This heuristic categorization also serves for communication and mutual understanding between different practitioners who deal with environmental aspects of economic or societal activities. It provides decision makers, environmental professionals, and scholars from different disciplines with a scheme for thinking outward and a common vocabulary for conceptualizing environmental impacts. Similarly, various regulations on economic and societal behaviour, such as emission limits, traffic speed limits, quotas for hunting, and restrictions on planning and construction, can be seen as special means for the general goal to control discharges to and intakes from the ecological environment. Moreover, no domain of economic activity is exempted from this scrutiny. The conventional categories of environmentally harmful activities do not usually include sports, for example, even though the environmental impacts of sports activities are not insignificant enough to be ignored (e.g. Stoddart 2011).

The heuristic value of this scheme derives from its pursuit of *overall* yet *systemic* understanding of environmental effects. The system of interest here is defined as broadly as possible – it is the human–environment interaction – and environmental problems are seen as a dimension of that system. The systemic approach we propose thus goes beyond being just 'systematic', which refers to procedures that follow *some* system or organized method. The current practice of environmental impact assessment (EIA), for example, includes a *systematic* analysis of environmental impacts, but given the broad variety of systems of interest (i.e. power plants, mines, motorways, etc.), the analyses rarely grasp environmental impacts in the *systemic sense* described above.

4.2 The architecture of an environmental problem

While the above heuristic helps to piece together environmental problems as a systemic dimension of human–environment interaction, it does not tell us how such problems come about. However, it sets a stage for a systemic consideration of that issue as well. The system of interest can be broadened so that the 'discharges' and 'intakes' become components of another system, the 'architecture' of an environmental problem. The structure and components of this wider system are described elsewhere ('Environmental Protection Process', see Willamo 2005; Tapio and Willamo 2008); here we discuss it as a heuristic tool for understanding what constitutes an environmental problem. While the actual procedure leading to the emergence of any particular problem is unique and too complex to lend itself to any single model, all problems can be treated as special cases of a generic pattern.

The pursuit of comprehensive understanding of environmental problem solving is not new. Process models for describing human–environment interaction with a view to tackling environmental problems have been developed in environmental sciences and management, and they are widely used in environmental policy and administration. Perhaps the most widely used is the Pressures-State-Response (PSR) framework, developed by the Organisation for Economic Cooperation and Development (OECD) in the 1980s. According to the framework, human activities cause 'pressure' on the environment, which influences the 'state' of the environment, and the deterioration of the environment then triggers 'responses' in society. The framework has been further developed by the European Environment Agency in the 1990s and 2000s, and its more recent version (DPSIR) distinguishes between 'pressures' and 'drivers' for them, as well as between the 'state' of the environment and the 'impacts' of this change. These frameworks have been important tools for comprehensive assessment and management of environmental issues (e.g. European Environment Agency 2003; Svarstad et al. 2007).

Like these frameworks, our heuristic connects environmental problems and their solutions to the interactions between the human (or societal) and environmental (or natural) systems. However, we make this distinction for heuristic purposes only, not to assume an ontological difference. Human society is an emergent construction of natural evolution, and is thus embedded in nature. However, due to their emergent properties, human systems follow different regularities than the rest of nature. While 'human system' and 'ecological system' are inseparable in the ontological sense, we argue that their conceptual distinction is helpful for making sense of how environmental problems come about. What defines these problems is their association with ecological exchange between human systems and ecological systems (see Section 4.1), and the various feedback mechanisms between the two systems.

It is exactly these interactions that the PSR and DPSIR frameworks aim to describe. However, as they do not problematize the nature of those interactions, they fail to recognize many contingent factors of environmental problems. For example, 'drivers' typically refer to industry, transport, agriculture, along with others, without addressing the underlying social and cultural structures in which they are embedded. Similarly, environmental changes are not distinguished from environmental problems, as if the latter followed directly from the former. In order to grasp the complexity of environmental problems, it is helpful to include the main sources of contingency into the framework that is used to describe them. Contingencies originate from the dynamics of both human and ecological systems as well as the way in which they interact. This implies that there is no pre-determined relationship between the components of environmental problems, but each problem can be characterized as a complex system.

Figure 2.2 presents our heuristic model for mapping what constitutes an environmental problem. As a heuristic for systemic understanding, it has two defining characteristics. First, it presents the major components of an environmental problem *as a complex system*, while aspiring for simplicity or 'thin description' (Brekhus et al. 2005). The model applies to many different settings, as far as the system of interest is a human-induced environmental change. Second, it takes account of the different dynamics of both human and ecological systems, and treats them as a duality. While not denying the central role of social factors in the very notion of environmental problem, our

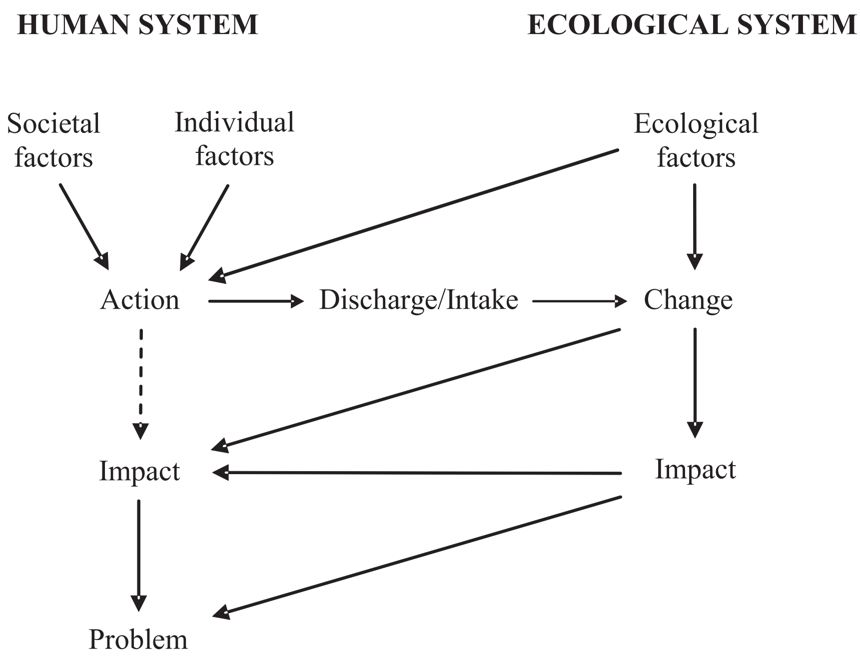

Figure 2.2 The architecture of an environmental problem (modified from Willamo 2005: Figure 21; Tapio and Willamo 2008: Figure 4).

approach can be set against a version of social constructivism that reduces nature to discourse about it and obscures the effects of the autonomous dynamics of nature (see Murphy 2007). In contrast to the latter view, we are interested in social constructions as important feedback links between human systems and ecological systems. The way ecological changes are perceived and dealt with depends on human systems, but these humanly constructed meanings themselves can be understood as having causal powers in humans' influence on ecological systems.

Due to its generalizability, the model serves as a checklist for analyzing the emergence and possible resolution of any environmental problem as a systemic whole. By applying this model it is possible to identify elements and stages in the process that easily go unrecognized (e.g. Nygrén et al. 2012; Varho et al. 2013). In this sense, it provides a descriptive heuristic that allows one to make interconnections between a broader range and diversity of variables. It portrays both the 'autonomous' dynamics of nature and human-induced changes in parallel, without assuming a dichotomy between them. At the same time, it distinguishes between environmental *change* as an ecological process occurring according to the natural laws on one hand and environmental *problem* as a socially defined phenomenon on the other hand – *as well as* the connection between them.

4.3 Heuristic list of interconnections involved in environmental issues

The two heuristic models described above help understand environmental issues in a systemic manner: the first model lays out human-induced environmental changes as a whole, and the second unpacks the structure of an environmental problem as a complex process. In addition to these 'variables', the complexity of environmental problems involves many other aspects. For example, environmental changes involve multiple causes and effects, with sometimes notable time lags, tipping points, and other nonlinear relationships included. They also tend to cross geographical, disciplinary, bureaucratic and other institutional boundaries, and intertwine with one another and with other societal problems. Moreover, they are frequently perceived as problematic for many different reasons. And the list of complex properties goes on. Table 2.2 presents a catalogue of measures or dimensions according to which environmental issues involve multiple perspectives and their interconnections. The table also suggests requirements for how to approach those complexities.

The table serves as a heuristic checklist of aspects or variables of environmental issues that can be successfully captured through outward thinking. In the beginning of an inquiry, it prevents premature closure of consideration or drift into a too narrow track of reasoning (cf. Abbott 2004). At a later stage, it helps connect the selected focus with other related issues and concerns. Checking the aspects listed in the table should open up possibilities to enrich

Table 2.2 Dimensions of environmental issues that can be grasped through outward thinking.

Dimension of environmental issues	*Categories relating to the dimension*	*Examples of interconnections between the categories*	*Implications for environmental research and problem solving*
Time	Past, present, future	Every environmental change has its history; environmental changes produced in a certain time can affect long in the future	The present-centred, short-term thinking has to be abandoned; learning from past mistakes, extending attention to the future
Space	Continents Countries Regions	Environmental changes produced at a certain place can affect places far away	Extensive mindset of local and global (with their intermediate forms) is needed
Cultures, states	'Western', 'Islamic', 'native'… Finland, Sweden, EU, USA…	People from different cultures and countries become involved in the same problems and conflicts	Cooperation between cultures and countries is needed
Societal or economic activities, actors and structures	Individuals and life styles Industry, transport, agriculture, consumption… Companies, hospitals, schools… Politics, science, education…	Everyone causes environmental change and is influenced by it (though some more than others) Many different activities cause the same environmental change	Cross-cutting concern: environmental conservation has to be taken into account in all activities The environmental impact of a social/economic activity should not only be assessed separately from other activities
Disciplines and fields	Disciplines Subjects	Environmental issues involve questions and applications pertaining to many different fields	Integration and cooperation between different fields is needed, including cooperation between natural sciences and humanities
Human problems	Poverty, hunger, inequality, environmental issues…	Hunger and poverty, among other things, are central causes for environmental issues particularly in the developing world	Problems should be handled as 'symptoms of the same disease', not only separately

Table 2.2 (continued)

Dimension of environmental issues	*Categories relating to the dimension*	*Examples of interconnections between the categories*	*Implications for environmental research and problem solving*
Levels of human-induced ecological change **(Heuristic 1)**	Energy flow Material circulation Structures and functions of living systems Structures and functions of macro-level mechanical systems	Human activities cause direct and indirect changes on all ecological levels and these different changes together create the 'system' of environmental problems, environmental crisis	Connections between the levels have to be taken into account, and none of the levels should dominate environmental research or problem solving
Environmental problems	Climate change, eutrophication, biodiversity degradation, noise, landscape change…	Single problems have multiple ecological and human connections to one another (e.g. the effects of climate change on biodiversity and landscape) A single human activity can cause different environmental problems; e.g. a moving car generates carbon monoxide, greenhouse gases, noise, and deaths of animals	See above
Factors behind environmental phenomena	Causal factors behind environmental changes (weather, pests, chemical pollutants, energy changes, mechanical procedures…) Factors that influence the outcome of environmental education (methods, contents, group dynamics, motivation…)	Environmental changes manifest in nature usually as multi-stress phenomena, i.e. combinations of many simultaneous effects Synergetic and antagonist interactions produce outcomes that differ from those produced by the factors operating individually	The linear 'x/y thinking', in which one factor (x) is referred to explain variation in another factor (y), is problematic; multivariable thinking should be pursued

Table 2.2 (continued)

Dimension of environmental issues	*Categories relating to the dimension*	*Examples of interconnections between the categories*	*Implications for environmental research and problem solving*
Process stages **(Heuristic 2)**	The emergence, manifestation and resolution/mitigation of environmental problems	The ecological manifestation and the social causes and consequences of an environmental problem are parts of the same process	Strong separation in observing the causes, manifestations and consequences of environmental problems is ineffective
Elements of ecological environment	Air, water, soil, living organisms	Interfaces of different physical states (e.g. water/sediment) are central in the dynamics of environmental change Air pollution affects water, soil and organisms Groundwater is 'inside the soil'	Strong division into environmental elements or sectors (e.g. the protection of air, water, soil, pristine nature) is ineffective
Hierarchical levels of organization	Cell, organ, individual, population and species level Individual, community and society level	Biodiversity occurs on every level of biological organization Society is constituted by individuals and individuals are constituted by society	Different levels of organization have to be understood in connection to one another, not as separate categories
Values in perceiving environmental problems	Ecological, ethical, aesthetic, economical, recreational, religious…	A given environmental change can be perceived (or not perceived) as a problem for different value-laden reasons	People with different values have to cooperate in environmental problem solving
Ways of engaging with the environment	Scientific, artistic, religious, bodily…	Together, the different ways of engaging with the environment form one's relationship to environment	All ways of engagement can contribute to environmental problem solving

Table 2.2 (continued)

Dimension of environmental issues	*Categories relating to the dimension*	*Examples of interconnections between the categories*	*Implications for environmental research and problem solving*
Dimensions of human mind	Knowledge, values, emotions, experiences…	Human perception of environmental problems depends on the interaction of these dimensions, not only on the processing of e.g. 'facts'	All dimensions of the human mind can enrich one's approach to environmental problem solving
Aspects of human existence	Human, ecological	Human beings are subordinate to the dynamics and exigencies of nature	Strong separation between human and nature is misguided

Notes: For each dimension, we give examples of various categories of thought and action, how these categories are linked, and what implications this has for environmental research and problem solving. The two heuristics discussed earlier in this section are also included in the table.

environmental analysis, whether for a strictly defined purpose or for a more open-ended inquiry.

For example, the 'time' factor can lead an Environmental Impact Analyst of a building project to think about the previous uses of the building site, the likely lifespan of the building, and the future of the site thereafter. It also reminds us of the cultural and social contexts of time (see Banister, Chapter 4, this volume). Similarly, the 'space' factor helps an analyst to observe both direct and indirect environmental effects. A certain amount of direct environmental effects (e.g. sound, waste) arises in the spatial proximity of a given target of analysis, whereas indirect effects occur beyond it. The latter include, for example, the effects caused by the production and transportation of energy, food, construction materials and other goods consumed in the target site.

The 'societal activities, actors and structures' dimension reminds an environmental analyst of the underlying connections between various social realities. In preparing for, say, a national report of the state of the environment, or environmental activities of an organization, one can get an idea of merging items that are usually treated on a sectoral basis. For example, human-induced noise is perceived, depending on context, either as an environmental issue or an occupational health issue. In many situations, it would make sense to combine these categories instead of reporting them separately – at least when they refer to the same sound.

The 'environmental problems' dimension refers to the typical classification between climate change, biodiversity loss, resource depletion, chemical accumulation and so forth. An environmental instructor, for instance, is reminded by this item to address connections between environmental problems right at the basic level, instead of scheduling one class on climate change, another on biodiversity loss, and so on. Students' cognitive conceptualization can be notably supported by considering links between problems (Willamo 2005: 74). An example of a systemic representation is that acidification primarily strains topographically high areas, which tend to be arid due to the weathering effect of water, whereas eutrophication causes problems in river valleys and lowlands, which are naturally rich in nutrients and in which human activity is also otherwise intensive. Besides noting that both phenomena have to do with, for example, nitrogen emissions, this linkage facilitates students' holistic understanding of the way human influence on the environment intertwines with the 'autonomous' dynamics of nature.

The history of environmental conservation is full of cases where this type of heuristic would have been useful. A canonical example is that the elements of ecological environment – air, water and soil – were perceived too strongly as three separate objects of protection. In Finland, which is rich in lakes, awareness of water pollution arose early and the Water Pollution Control Act came into effect as early as 1962. Air Pollution Control Act did not take effect until 1982, but soil was at the time not yet properly considered as an object to be protected from pollution. Specific law for soil pollution control was never enacted but statutes concerning soil were later incorporated into different laws. This time lag in the 'discovery' of soil as an object of conservation still has repercussions on Finnish environmental protection.

'Hierarchical levels' arrange related items vertically, but sometimes the links between different levels are lost. For example, in the Convention on Biological Diversity, founded at the Earth Summit in Rio de Janeiro in 1992, biological diversity was defined broadly as 'variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part' (UN 1992: 3). Later on, however, biodiversity has come to be understood to cover only three hierarchical levels: 1) genetic, 2) species, and 3) ecosystem diversity. This classification is widely established in the discussion on biodiversity (e.g. Miller 1996: 26; UNEP 2013). However, biological diversity manifests also on other levels, including the level of individual organisms. Each individual is different from one another, not only in their biological inheritance but also in their life history adaptations, and thus contributes to biological diversity. Inattention to individuals in conceptions of biodiversity has left discussion on animal rights in a dubious position. As the diversity of individuals is not counted as part of biodiversity, advocating animal rights is not always perceived as 'proper' environmentalism, even though the topic is important in environmental philosophy (e.g. Singer 1975; Taylor 1981).

Perhaps the most important dimension of Table 2.2 is the last item, 'aspects of human existence': despite the 'human' side of this existence, a human being is subordinate to the dynamics and exigencies of nature. Nevertheless, the mental and the bodily dimensions of our relationship to nature are often perceived and presented separately in research and education (see Woodgate and Redclift 1998). In the concepts of environmental education, for example, one's 'relationship to nature' often refers exclusively to one's mental constructs of nature; one's bodily functions, in turn, are solely biological matters that are not incorporated into the concept. Individual human beings are thus portrayed to have a relationship to nature with their knowledge, values and emotions, but without their metabolism, need of oxygen, immune system and so on. This is an absurd consequence of disjunctive thinking.

Overall, these kinds of considerations open up complexities involved in environmental issues due to their coupled relationship with many different systems. In a single inquiry, it is nonetheless important to focus on one or few dimensions and to avoid mixing them up; otherwise, there is an obvious risk of expanding the analysis too much or losing attention.

5 Conclusions

The complexity of environmental problems suggests searching for solutions at a systemic level. Due to the nature of human-ecological systems as open systems consisting of many parts that interact in an intricate manner, improving one component of a system may lead to further problems elsewhere. Any such solution appears partial and unsatisfactory when seen from a higher systemic level. As correctly judged by Ulrich (1994: 35), ‘the implication of the systems idea is not that we must understand the whole system, but rather that we critically deal with the fact that we never do’. According to Preiser and Cilliers (2010), this attitude provides us with the methodological basis for developing tools of critical reflection.

In this chapter, we have discussed a cognitive strategy and heuristics for dealing with the complexity of environmental issues. Our primary goal has been to contribute to environmental analysts’ general ability to recognize emergent properties and patterns of human-environmental interaction, construed from the overall perspective of environmental problematique. We have not so much been concerned with theorizing about this interaction as with facilitating systemic understanding and problem solving in different environmental settings. Complexity emerges in context-specific ways, but analogical reasoning and abstraction allows for comparing similar events, activities, or phenomena despite their situational variation (cf. Zerubavel 2007). What is appropriate and purposeful in one situation can be informed by other related situations, even if the situations cannot be treated as ‘cases’ of a similar kind or a general rule due to the emergent properties involved. Holistic understanding of a particular case is not transferable in any unequivocal sense, but may inform pattern recognition across cases.

While pattern-matching ability is a form of tacit knowledge that indicates the highest level of mastering a skill (Flyvbjerg 2001), we have suggested relatively simple heuristics that may guide the search for patterns amongst the complexity of environmental issues. We have discussed a cognitive strategy through which individuals, organizations, or other observers can consciously move outwards from their initial object of interest and thereby construct a new understanding of the situation from a broader scope. This may trigger changes in the underlying categories of thought and action and lead to a more holistic conceptualization of the situation. The ultimate aim of this strategy is to create cognitive conditions in which systemic understandings can emerge. Responsible conceptualization of problems requires awareness of other alternative framings, and a selection of one that is relevant for the task at hand (McClintock et al. 2003).

There is a bunch of evidence in environmental history that shows the need for the kind of outward thinking we have proposed in this chapter. For example, the various ways in which humans alter energy flows have received surprisingly little attention in modern environmental thinking compared to chemical pollution (see e.g. Miller 1979; Cunningham and Saigo 1992; Chiras 2001). This is understandable given the dramatic impacts of chemicals on ecosystems and human health, but indicates a failure of systemic attention to human interference in the dynamics of nature. Recent discussion on energy emissions has brought a lot of new knowledge of the effects of lighting, noise, electromagnetic fields and so on, which would have been possible to anticipate on the basis of the experience with chemical emissions.

Problems with pigeonholing are not limited to scientific understanding, but strongly influence practice. Our example of the exclusion of sports from the sphere of environmental regulation indicates that economic activities may end up in unequal positions due to the lack of systemic attention to environmental effects – neither objective assessment nor public deliberation is being conducted to exempt sports from environmental control. In general, the inclusion and exclusion of items in existing categories have long-term political and ethical implications (Bowker and Star 1999; Connolly 2002; Haraway 1985).

We have illustrated three heuristics for grasping environmental problems as systemic outcomes of human–environment interaction, or as 'mismatches' between the dynamics of human systems and the dynamics of nature. These are heuristics in the aforementioned sense: they aim at facilitating environmental understanding and problem solving in particular situations in a way that allows for alignment and comparison across situations and thereby for a more systemic comprehension and treatment of environmental issues.

Besides being tools for systemic understanding and problem solving, the three heuristics are also products of the cognitive strategy of outward thinking. The first one, search tool for human-induced environmental change, as well as the third one that sums up interconnections involved in environmental issues, are examples of new classification schemes created by outward thinking. The second heuristic, the architecture of an environmental problem, is a product of a more focused attempt to extend and integrate the analytic dimensions of previous process models through horizontal thinking.

The most obvious functions of the proposed heuristics are their usage as checklists on the one hand and as challengers of existing boundaries on the other hand. As *checklists*, they provide comprehensive categories or topics that relate to the object of interest – types of direct environmental effects of human activity in the first case; structural components of an environmental problem in the second case; and a list of interconnections involved in environmental issues in the third case. A special strength of the first heuristic is its theoretical coverage of all types of human-induced direct ecological effect (discharges and intakes), whereas the second heuristic is generalizable to any human-induced environmental change. Both heuristics can thus function as wide-ranging and strong checklists that facilitate systemic attention to human–environment interaction from their respective points of observation. As *challengers* of existing boundaries in environmental thinking, all three heuristics illustrate systemic links between things that are frequently sorted out from each other. Overall, the heuristics ensure that institutionalized categories and forms of analysis are not mechanically applied in sustainability problem solving, which clearly requires entirely new ways of thought and action.

References

Abbott, A. (2004) *Methods of Discovery: Heuristics for the Social Sciences*, Series: Alexander, J.C. (ed.) Contemporary Societies, New York & London: W.W. Norton & Company.

Ayres, R. U. and Ayres, L. (eds) (2002) *A Handbook of Industrial Ecology*, Cheltenham: Edward Elgar Publishing.

Barry, A., Born, G. and Weszkalnys, G. (2008) 'Logics of interdisciplinarity', *Economy and Society*, 37: 20–49.

Berninger, K., Tapio, P. and Willamo, R. (1996) *Ympäristönsuojelun perusteet*, Helsinki: Gaudeamus.

Brekhus, W.H., Galliher, J.F. and Gubrium, J.F. (2005) 'The need for thin description', *Qualitative Inquiry*, 11(6): 861–79.

De Bono, E. (1970) *New Think: The Use of Lateral Thinking in the Generation of New Ideas*, New York: Basic Books.

Bowker, G.C. and Star, S.L. (1999) *Sorting Things Out: Classification and Its Consequences*, Cambridge, MA: MIT Press.

Bowler, P.J. (1992) *The Fontana History of Environmental Sciences*, Fontana History of Science Series, London: Fontana Press.

Byrne, D. (2010) 'Comparison, diversity and complexity', in Cilliers, P. and Preiser, R. (eds) *Complexity, Difference and Identity*, Issues in Business Ethics, vol. 26, Dordrecht: Springer

Carson, R. (1962) *Silent Spring*, Boston, MA: Houghton Mifflin Company.

Chiras, D. D. (2001) *Environmental Science. Creating a Sustainable Future*, 6th edition, Sudbury, MA: Jones and Bartlett Publishers.

Cilliers, P. (2010) 'Difference, identity and complexity', in Cilliers, P. and Preiser, R. (eds) *Complexity, Difference and Identity*, Issues in Business Ethics, vol. 26, Dordrecht: Springer.

Cilliers, P. and Preiser, R. (eds.) (2010) *Complexity, Difference and Identity.* Issues in Business Ethics, vol. 26. Dordrecht: Springer.

Commoner, B. (1971) *The Closing Circle: Nature, Man, and Technology*, New York: Knopf.

Connolly, W.E. (2002) *The Augustinian Imperative: A Reflection on the Politics of Morality*, Lanham, MD: Rowman & Littlefield.

Cunningham, W.P. and Saigo, B.W. (1992) *Environmental Science: A Global Concern*, Dubuque, IA: WCB.

European Environment Agency (1999) *Information for improving Europe's environment. An introduction to the European Environment Agency*, Copenhagen, Luxembourg: Office for Official Publications of the European Communities.

——(2003) *Europe's Environment: The Third Assessment*, Environmental assessment report No 10. Available at http://reports.eea.eu.int/environmental_assessment_report_2003_10

Flyvbjerg, B. (2001) *Making Social Science Matter: Why Social Inquiry Fails and How It Can Succeed again*, Cambridge, UK: Cambridge University Press.

Gupta, H. K. (2002) 'A review of recent studies of triggered earthquakes by artificial water reservoirs with special emphasis on earthquakes in Koyna, India', *Earth-Science Reviews*, 58(3–4): 279–310.

Hagenah, E. (1999) 'A regulatory view on science and predictive models', *Environmental Pollution*, 100: 13–18.

Haraway, D. (1985) 'A manifesto for Cyborgs: Science, technology and social feminism in the 1980s', *Socialist Review*, 80: 65–108.

Huijser, M.P. and Bergers, P.J.M. (2000) 'The effect of roads and traffic on hedgehog (*Erinaceus europaeus*) populations', *Biological Conservation*, 95(1): 111–16.

Ison, R. (2010) *Systems Practice: How to Act in a Climate Change World*, Dordrecht: Springer.

——(2011) 'Cybersystemic conviviality: Addressing the conundrum of ecosystem services', *Cybernetics and Human Knowing*, 18(1–2): 135–41.

Ison, R. and Russell, D.B. (2000) 'Exploring some distinctions for the design of learning systems', *Cybernetics and Human Knowing*, 7(4): 43–56.

Jasanoff, S. (2004) *States of Knowledge: The Co-Production of Science and the Social Order*, London: Routledge.

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grübler, A., Huntley, B., Jäger, J., Jodha, N.S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore, B., O'Riordan, T. and Svedin, U. (2001) 'Sustainability science', *Science*, 292(5517): 641–42.

Latour, B. (2004) *The Politics of Nature*, Cambridge, MA: Harvard University Press.

Laukkanen, T. and Huutoniemi, K. (2006) 'Sektoreista integraatioon: Ilmansuojelun kehityksen tarkastelua', in Huutoniemi, K., Estlander, A., Hahkala, M., Hämekoski, K., Kulmala, A., Lahdes, R. and Laukkanen, T. (eds) *Savuntarkastajista päästökauppiaisiin: Suomalaisen ilmansuojelun historiaa*, Helsinki: Finnish Air Pollution Prevention Society.

Law, J. (2004) *After Method: Mess in Social Science Research*, London and New York: Routledge.

Leopold, A. (1949) *A Sand County Almanac and Sketches Here and There*, New York: Oxford University Press.

Levin, S.A. (1992) 'The problem of pattern and scale in ecology', *Ecology*, 73(6): 1943–67.

Liverman, D. (1999) 'Geography and the global environment', *Annals of the Association of American Geographers*, 89(1): 107–20.

Lovelock, J. (1979) *Gaia, a New Look at Life on Earth*, Oxford: Oxford University Press.

Lyytimäki, J. and Rinne, J. (2013) 'Voices for the darkness: Online survey on public perceptions on light pollution as an environmental problem', *Journal of Integrative Environmental Sciences*, 10(2): 127–39.

Lyytimäki, J. and Tapio, P. (2009) 'Climate change as reported in the press of Finland: From screaming headlines to penetrating background noise', *International Journal of Environmental Studies*, 66(6): 723–35.

Manninen, S. and Willamo, R. (1993) 'Ympäristön laadun ohjearvot Suomessa: Arvoja ja arvioita', *Ernvironmentalica Fennica*, 17, Helsinki: Helsinki University Press.

McClintock D., Ison, R. and Armson, R. (2003) 'Metaphors for reflecting on research practice: Researching *with* people', *Journal of Environmental Planning and Management*, 46(5): 715–31.

Meadows, D.H. (1999) *Leverage Points: Places to Intervene in a System*, Hartland, VT: The Sustainability Institute.

Meadows, D.H., Meadows, D.L., Randers, J. and Behrens III, W.W. (1972) *The Limits to Growth*, London: Earth Island Limited.

Miller, G.T. Jr (1979) *Living in the Environment*, 2nd edition, Belmont, CA: Wadsworth Publishing Company.

——(1996) *Sustaining the Earth: An Integrated Approach*, 2nd edition, Belmont, CA: Wadsworth Publishing Company.

Morin, E. (2008) *On Complexity*, Cresskill, NJ: Hampton Press.

Murphy, R. (2007) 'Thinking across the culture/nature divide: An empirical study of issues for critical realism and social constructionism', in Frauley, J. and Pearce, F. (eds) *Critical Realism and the Social Sciences*, Toronto: University of Toronto Press.

——(2012) 'Sustainability: A wicked problem', *Sociologica*, 2/2012.

Musters, C. J. M., de Graaf, H.J. and ter Keurs, W.J. (1998) 'Defining socio-environmental systems for sustainable development', *Ecological Economics*, 26(3): 243–58.

Nuorteva, P. (1990) 'Metal distribution patterns and forest decline. Seeking Achilles' heels for metals in Finnish forest biocoenoses', *Publications of the Department of Environmental Conservation at the University of Helsinki*, No. 11.

Nygrén, N. A., Lyytimäki, J. and Tapio, P. (2012) 'A small step toward environmentally sustainable transport? The media debate over the Finnish carbon dioxide-based car tax reform', *Transport Policy*, 24: 159–67.

Odum, E.P. (1971) *Fundamentals of Ecology*, 3rd edition, Philadelphia, London, Toronto: W. B. Saunders Company.

Ostrom, E. (2009) 'A general framework for analyzing sustainability of social-ecological systems', *Science*, 325: 419–22.

Preiser, R. and Cilliers, P. (2010) 'Unpacking the ethics of complexity', in Cilliers, P. and Preiser, R. (eds) *Complexity, Difference and Identity*, Issues in Business Ethics, vol. 26, Dordrecht: Springer.

Prigogine, I. and Stengers, I. (1984) *Order out of chaos: Man's dialogue with nature*, New York: Bantam.

Sarewitz, D. (2010) 'Against holism', in Frodeman R., Klein, J.T. and Mitcham, C. (eds) *The Oxford Handbook of Interdisciplinarity*, Oxford: Oxford University Press.

Schlindwein, S.L. and Ison, R. (2004) 'Human knowing and perceived complexity: Implications for systems practice', *Complexity and Organization*, 6(3): 27–32.

Schmidt-Bleek, F. (1993) *Wieviel Umwelt braucht der Mensch? MIPS – das mass für ökologisches Wirtschaften*, Berlin: Birkhäuser Verlag.

Schön, D.A. (2001) 'The crisis of professional knowledge and the pursuit of an epistemology of practice', in Raven, J. and Stephenson, J. (eds) *Competence in a Learning Society*, New York: Peter Lang.

Singer, P. (1975) *Animal Liberation: A New Ethics for our Treatment of Animals*, New York: New York Review/Random House.

Stoddart, M.C.J. (2011) '"If we wanted to be environmentally sustainable, we'd take the bus": Skiing, mobility and the irony of climate change', Human Ecology Review, 18(1): 19–29.

Svarstad, H., Petersen, L.K., Rothman, D., Siepel, H., Wätzold, F. (2007) 'Discursive biases of the environmental research framework DPSIR', *Land Use Policy*, 25: 116–25.

Tapio, P. and Willamo, R. (2008) 'Developing interdisciplinary environmental frameworks', *Ambio*, 37(2): 125–33.

Taylor, P.W. (1981) 'The ethics of respect for nature', *Environmental Ethics*, 3(3): 197–218.

Ulrich, W. (1994) 'Can we secure future-responsive management through systems thinking and design?', *Interfaces*, 24: 26–37.

UN, United Nations (1992): *Convention on Biological Diversity*. Available at http://www.cbd.int/convention/text.

UNEP, United Nations Environment Programme (2013) *What is biodiversity?* Available at: http://www.unep-wcmc.org/what-is-biodiversity_50.html.

Varho, V., Nygrén, N.A. and Lyytimäki, J. (2013) 'Transport discussion amidst climate challenges: Analysing student, media, and expert framings through the Environmental Protection Process model', *Transportation Research Part D: Transport and Environment*, 24 (October): 10–16.

Willamo, R. (2005) *Kokonaisvaltainen lähestymistatapa ympäristönsuojelutieteessä. Sisällön moniulotteisuus ympäristönsuojelijan haasteena*. Environmentalica Fennica 23, University of Helsinki.

Woodgate, G. and Redclift, M. (1998) 'From a "sociology of nature" to environmental sociology: Beyond social construction', *Environmental Values*, 7: 3–24.

Zerubavel, E. (2007) 'Generally speaking: The logic and mechanics of social pattern analysis', *Sociological Forum*, 22(2): 131–45.